

Overview of TJ-II Flexible Heliac Experiments

C. Alejaldre
(for the TJ-II Team)

LABORATORIO NACIONAL DE FUSION
Asociación EURATOM-CIEMAT
MADRID

TJ-II Team



C. Alejaldre, J. Alonso, L. Almoguera, E. Ascasíbar,
A. Baciero, R. Balbín, M. Blaumoser, J. Botija, B. Brañas,
E. de la Cal, A. Cappa, R. Carrasco, F. Castejón,
J. R. Cepero, C. Cremy, J. M. Delgado, J. Doncel,
T. Estrada, A. Fernández, C. Fuentes, A. García, I. García,
J. Guasp, J. Herranz, C. Hidalgo, J. A. Jiménez,
I. Kirpitchev, V. Krivenski, F. Lapayese, K. Likin,
M. Liniers, A. López-Fraguas, A. López-Sánchez, E. de la
Luna, R. Martín, A. Martínez, L. Martínez, M. Medrano,
P. Méndez, K. McCarthy, F. Medina, B. van Milligen,
M. Ochando, L. Pacios, I. Pastor, M.A. Pedrosa, A. de la
Peña, A. Portas, J. Qin, L. Rodríguez-Rodrigo, A. Salas,
E. Sánchez, J. Sánchez, F. Tabarés, D. Tafalla, V. Tribaldos,
J. Vega and B. Zurro.

Outline

- Introduction
- Profiles
- Resonance Studies
- Transport Barriers
- ELM-like behaviour
- Summary/conclusions

TJ-II Coils

$$R_0 = 1.50 \text{ m.}$$

$$a = 0.20 \text{ m.}$$

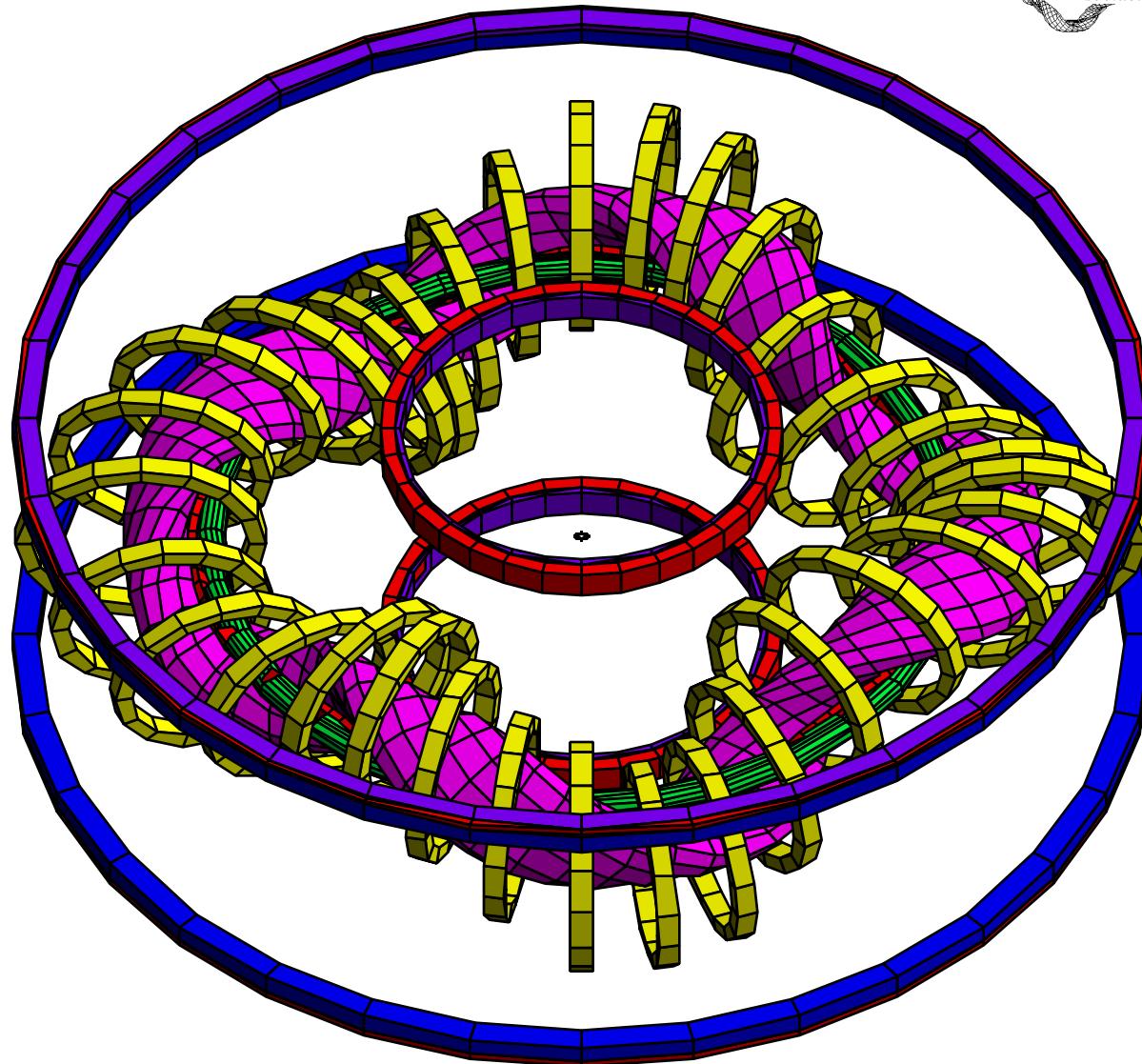
$$B_0 = 1.00 \text{ T.}$$

$$M = 4$$

$$r_c = 0.425 \text{ m.}$$

$$r_{ht} = 0.28 \text{ m.}$$

$$r_{hh} = 0.07 \text{ m.}$$



TJ-II parameters



Number of periods	4	
Vacuum Vessel Diameter	5	m
Circular Coil Diameter	3	m
Average magnetic field	≤ 1.2	T
Pulse length	≤ 1	s
Number of TF coils	32	
TF coil swing	0.28	m
Maximum circular coil current	280	kA
Maximum helical coil current	260	kA
Maximum VF current	200	kA
Plasma Volume	≤ 1.30	m^3
Average Plasma radius	≤ 0.25	m
Shear range	-1 % --> +10	%
Rotational transform range	0.96 --> 2.5	
Magnetic well depth range	0 --> 6	%

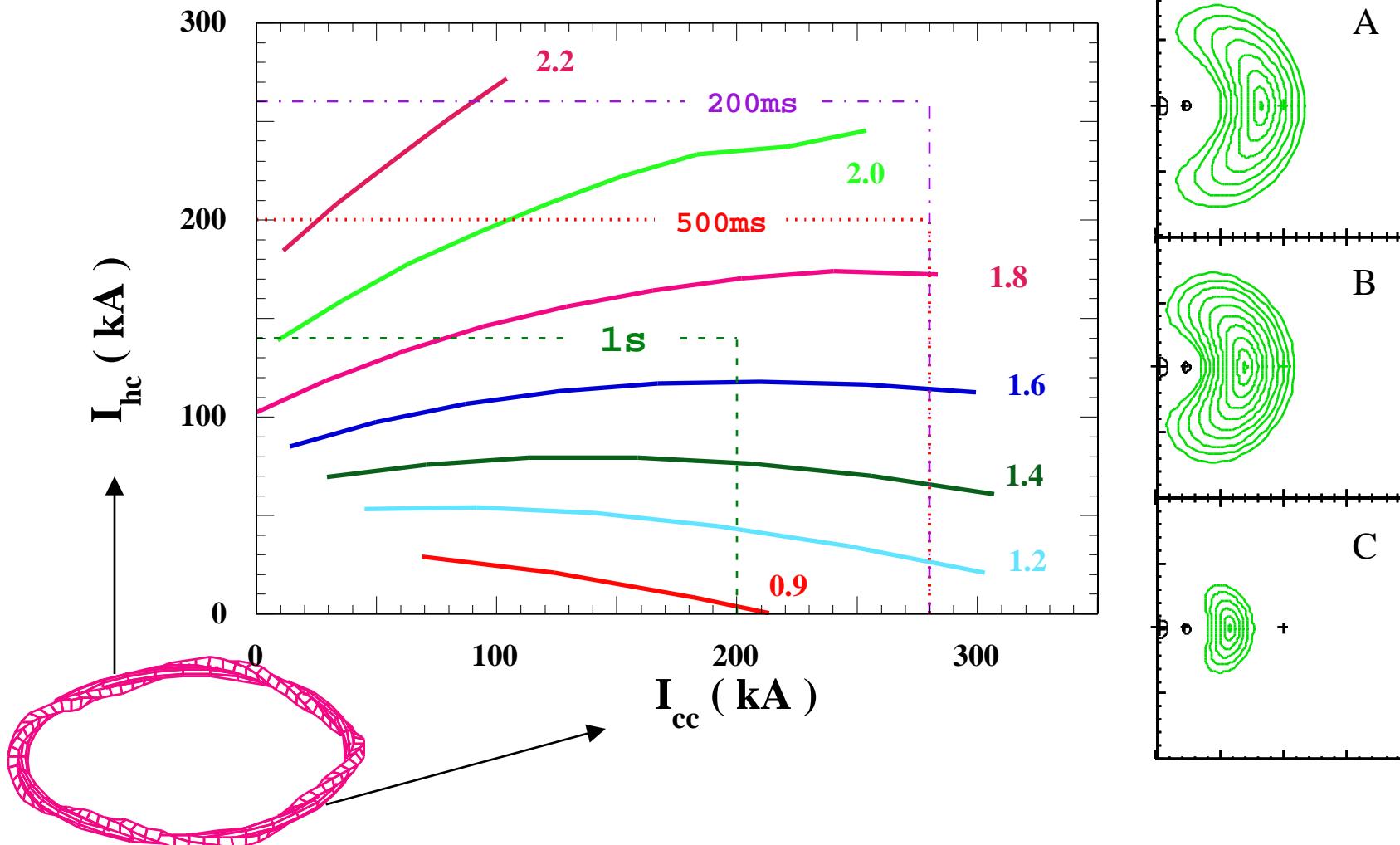
Latest Improvements



- Installation Vacuum Vessel Baking (150°)
- Second ECRH (300 kW in VV) quasi-optical transmission line with movable mirror (QTL 2):
 - QTL 2 power density at resonance 25 W/cm³
 - QTL 1 power density at resonance 1 W/cm³
- New diagnostics (atomic beams, HIBP,...)
- NBI Under installation...

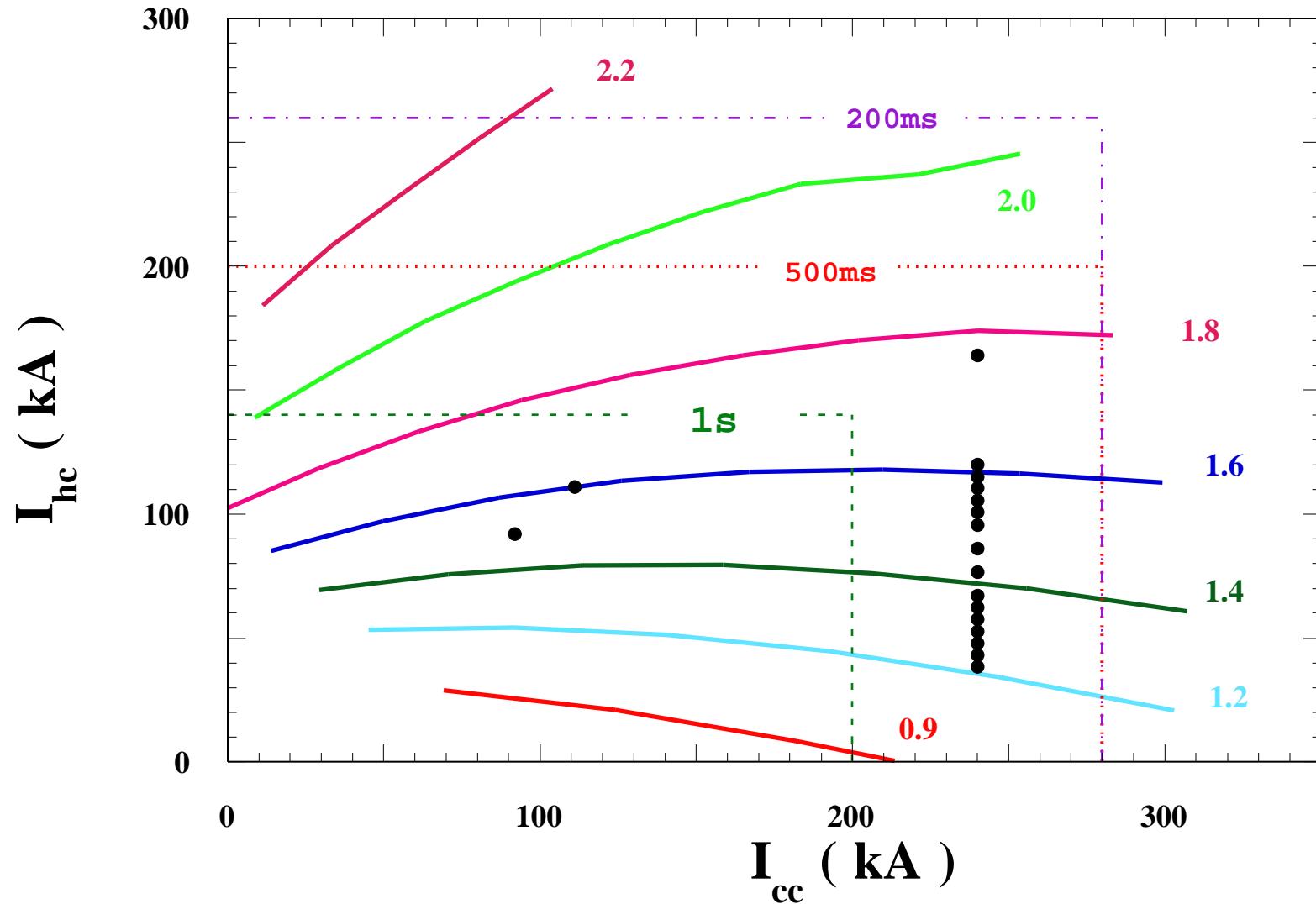
Flexibility Diagram

TJ-II is able to achieve a wide variety of configurations
with very different physical properties



Studied Configuration Range

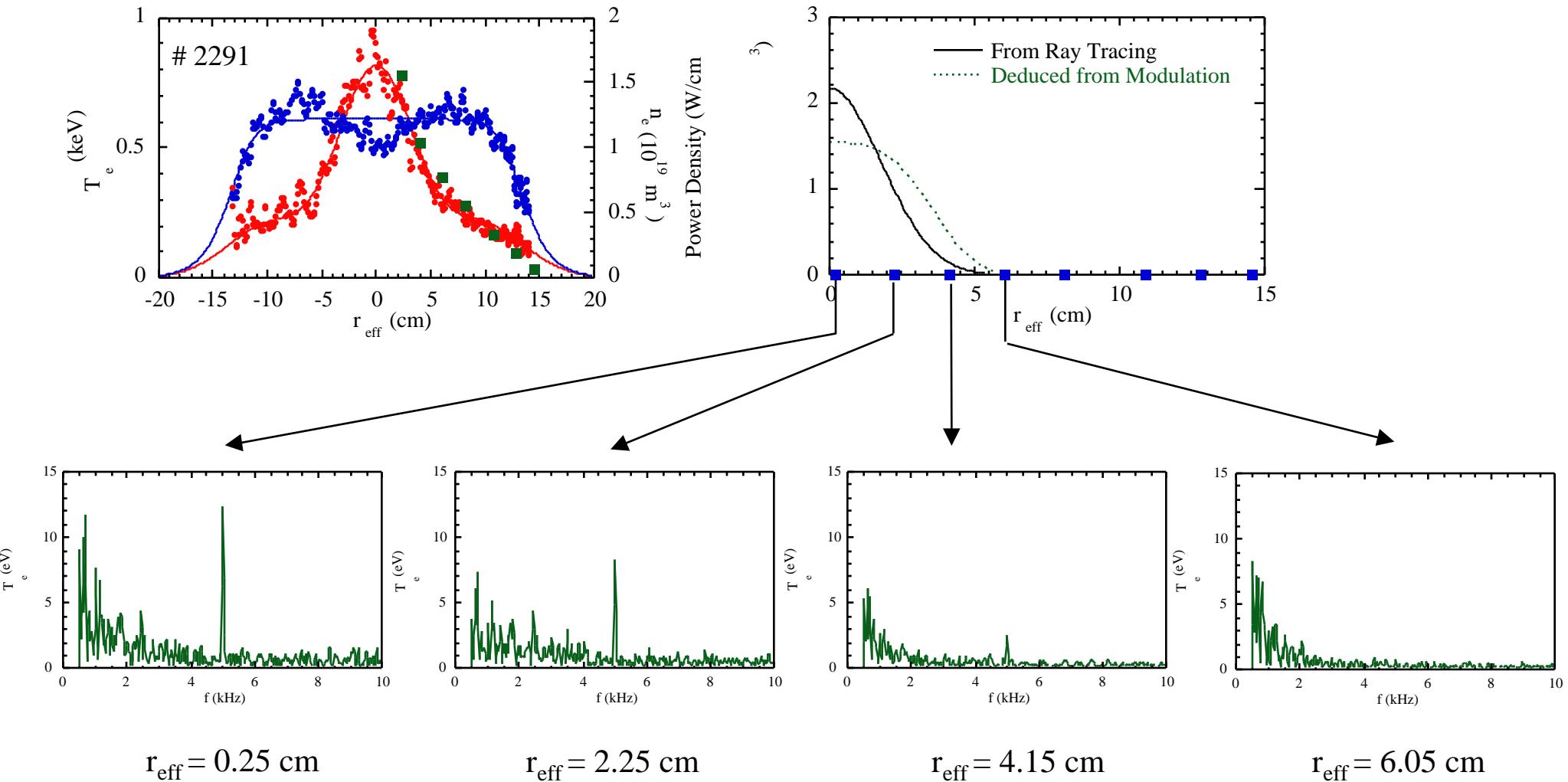
Only a small fraction of the wide operational space has been explored so far.



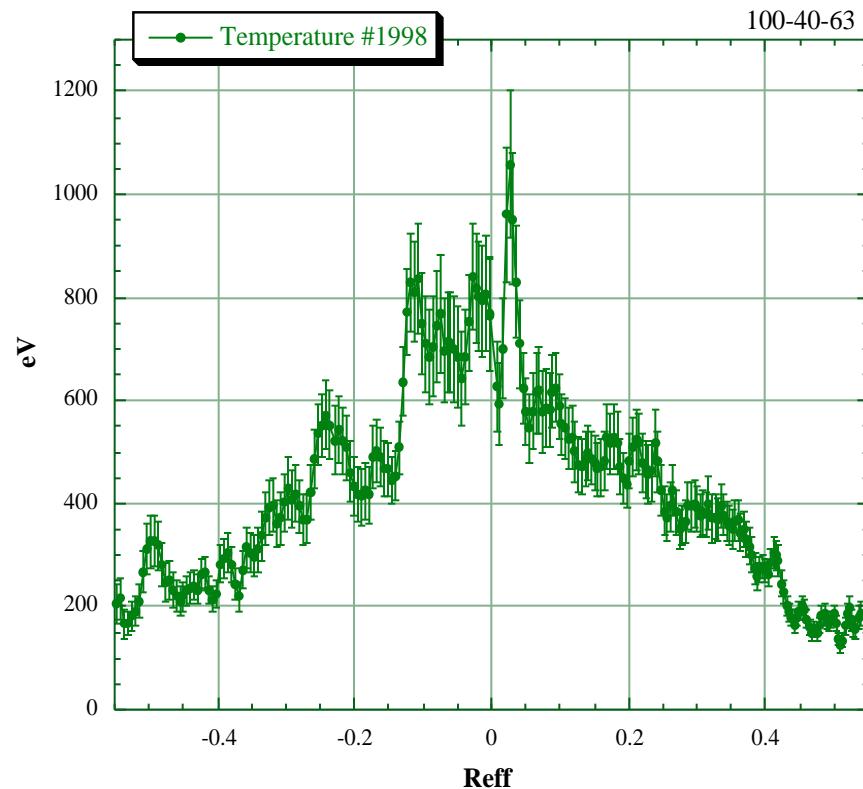
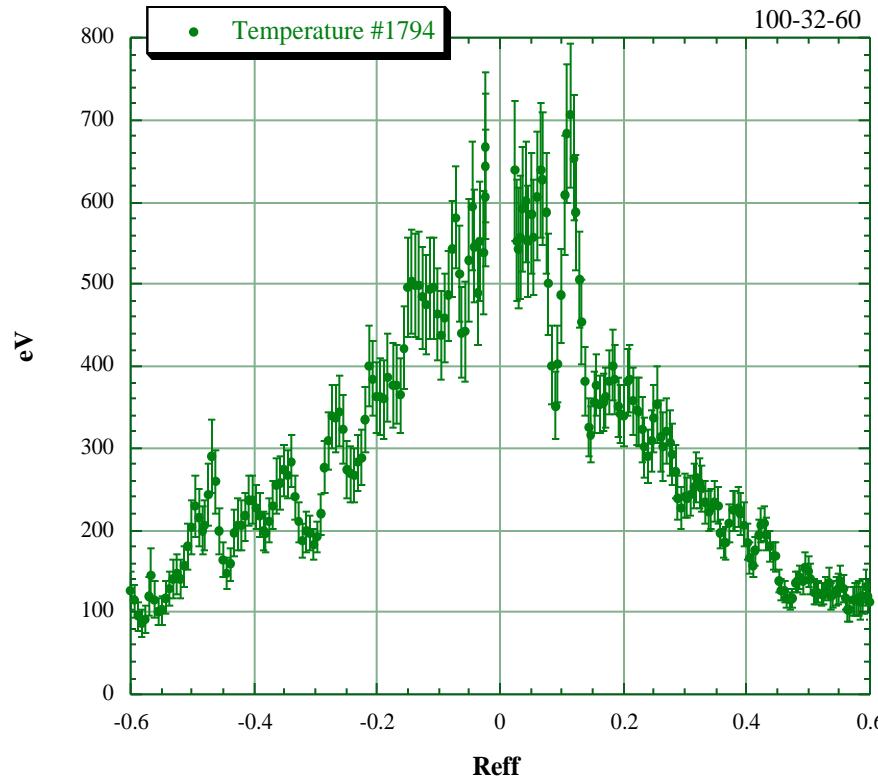
ECRH Power Modulation



$$P_{\text{ECRH}} = P_{\text{QTL1}}(300 \text{ kW}) + P_{\text{QTL2}}(100 \text{ kW}; 5 \text{ kHz})$$

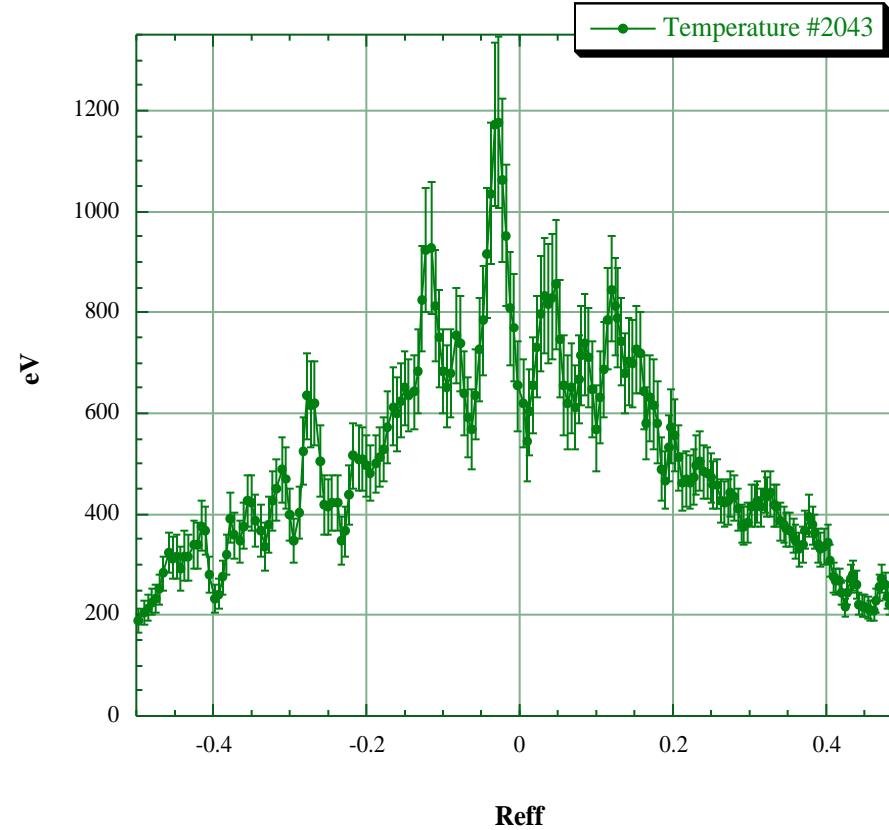
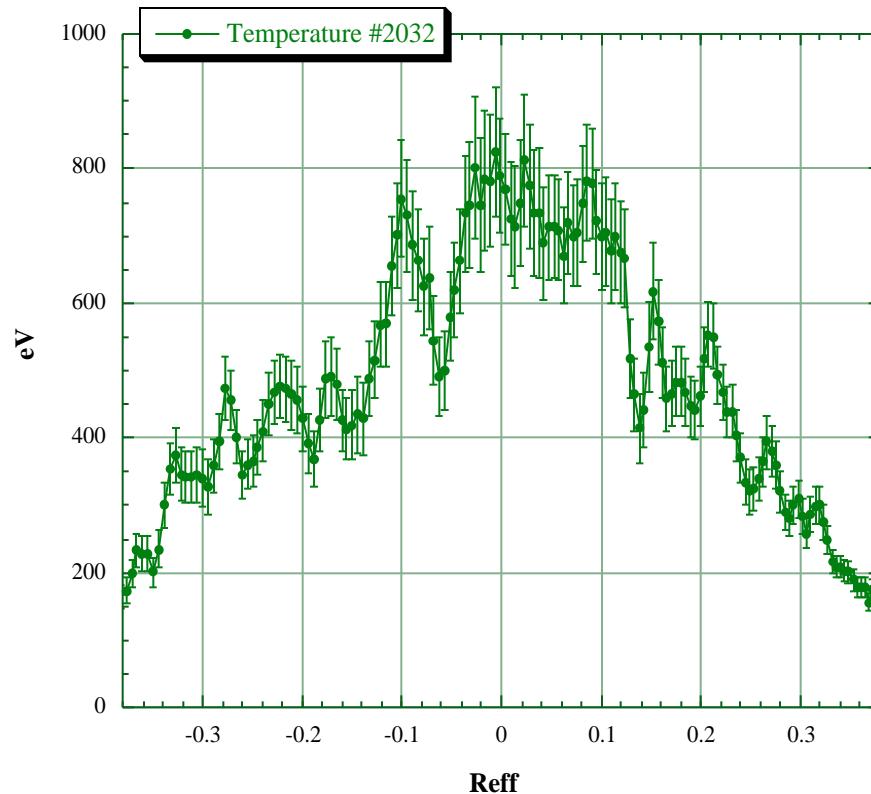


Profile structures (I)

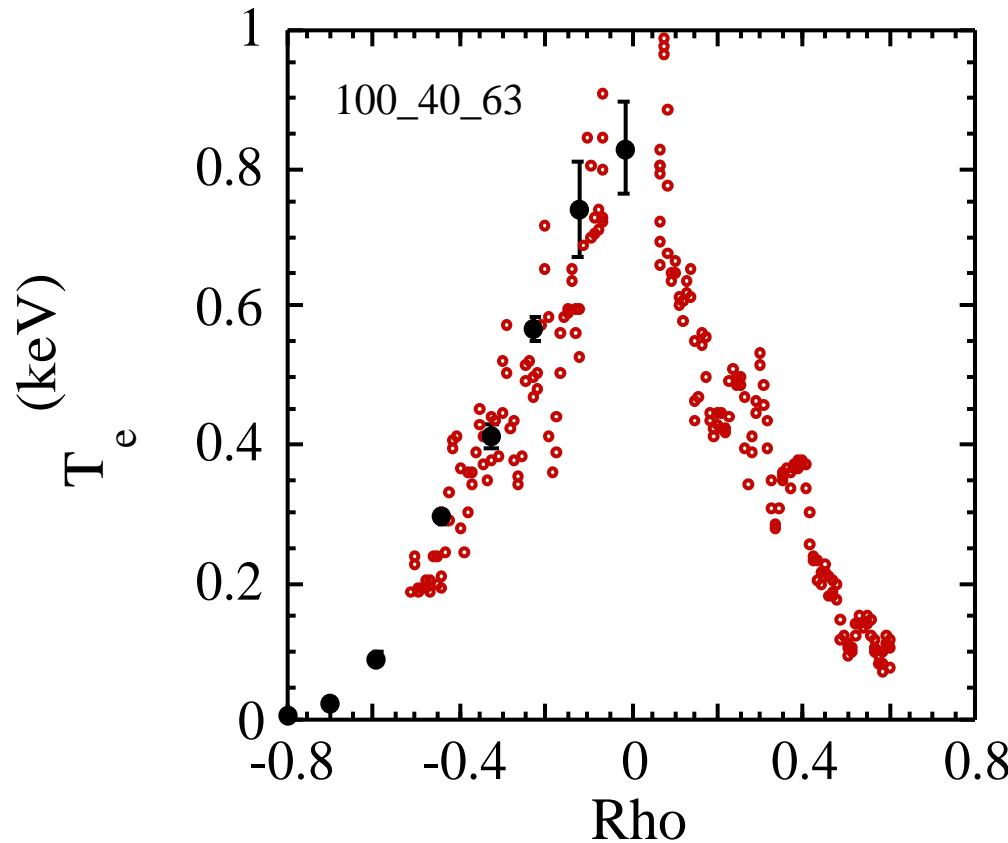


Small scales structures are observed in the temperature profile, in different plasma conditions and along the effective radius

Profile structures (II)



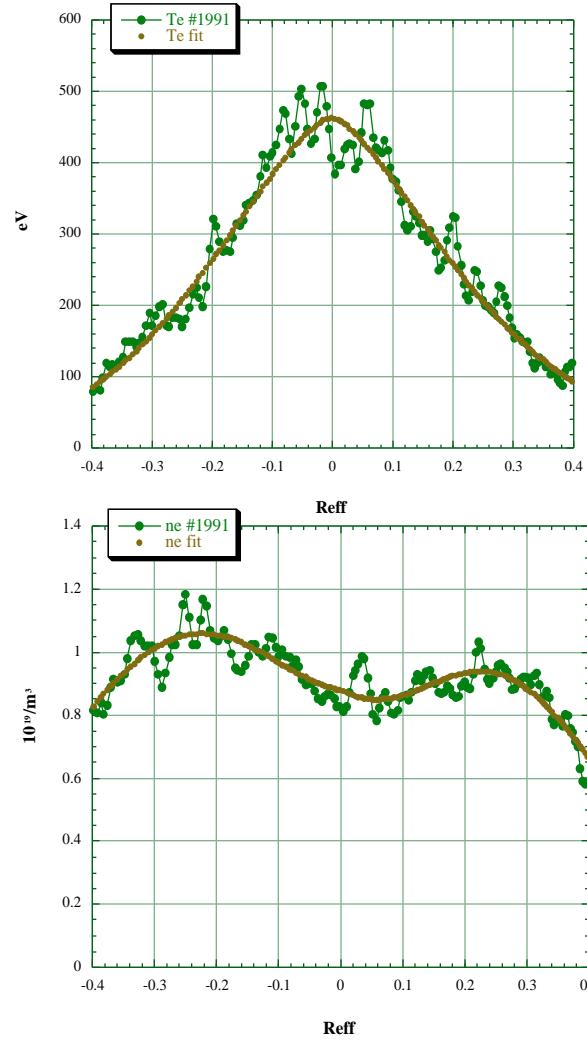
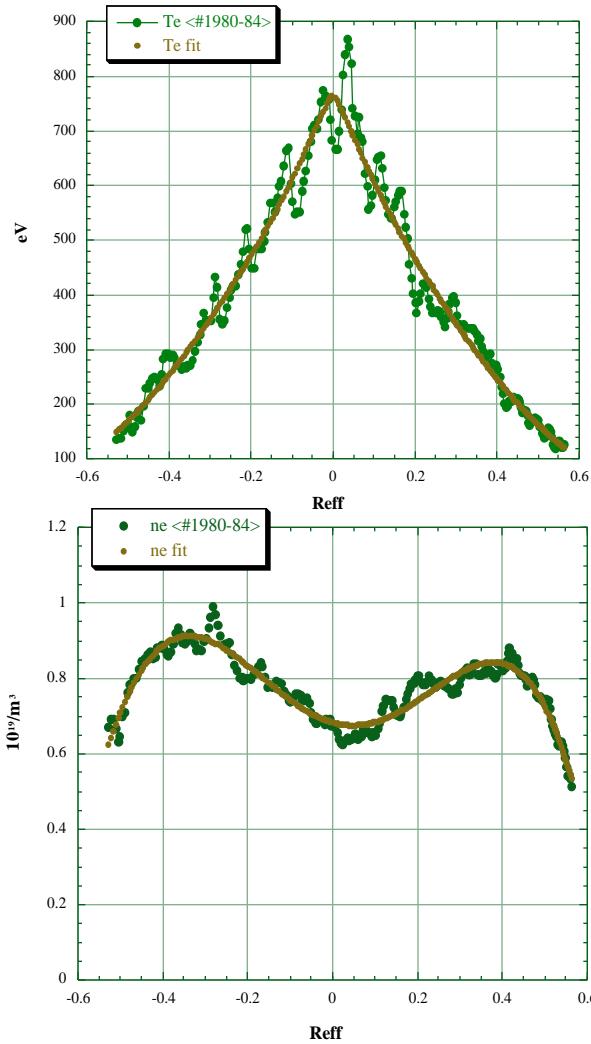
Plasma profiles: ECE versus Thomson



Thomson scattering and ECE system measurements (in excellent agreement) show peaked temperature profiles but rather flat density profiles, in on-axis ECRH.

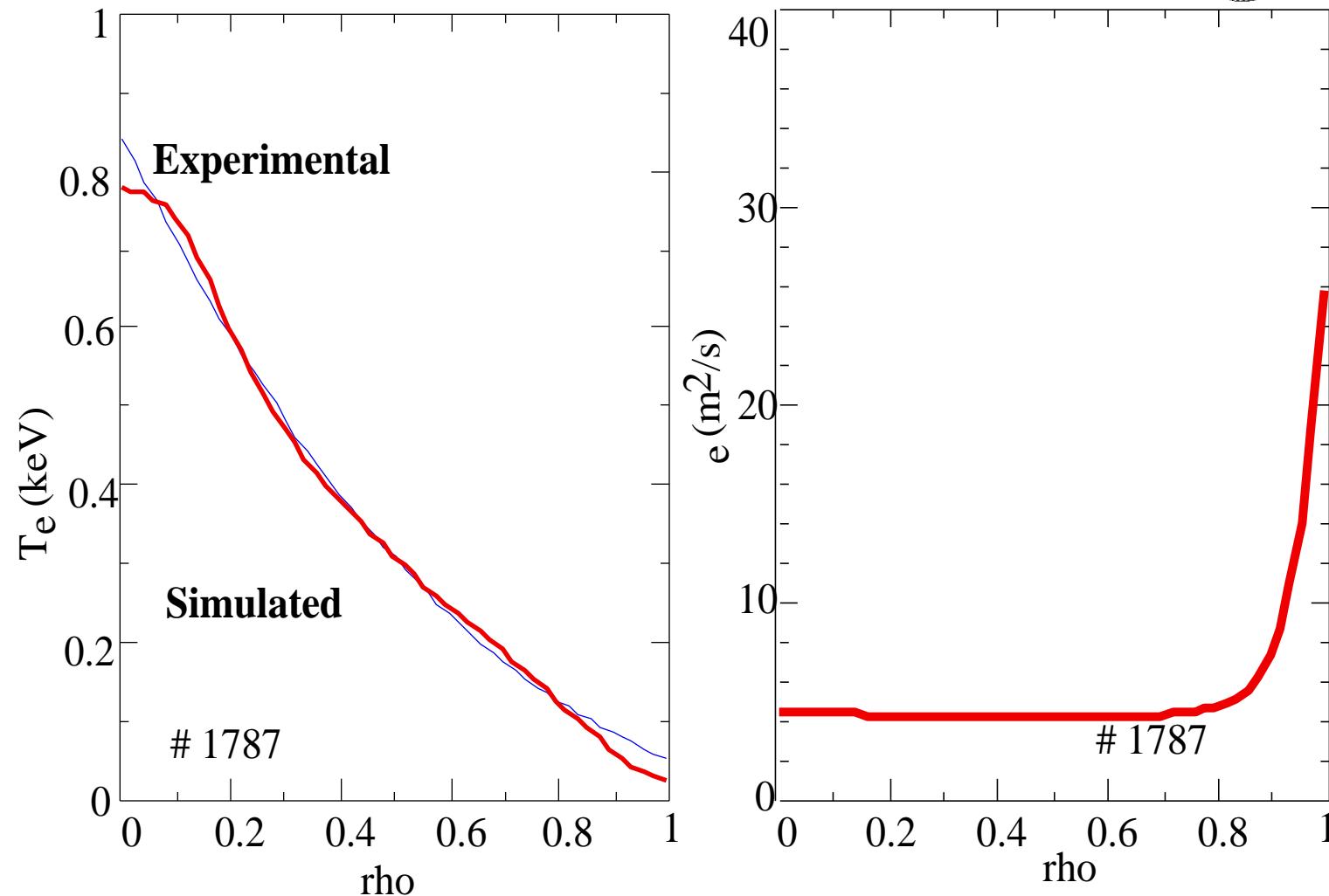
Poloidal rotation measurements: 1-10 km/s

Temperature and density profiles

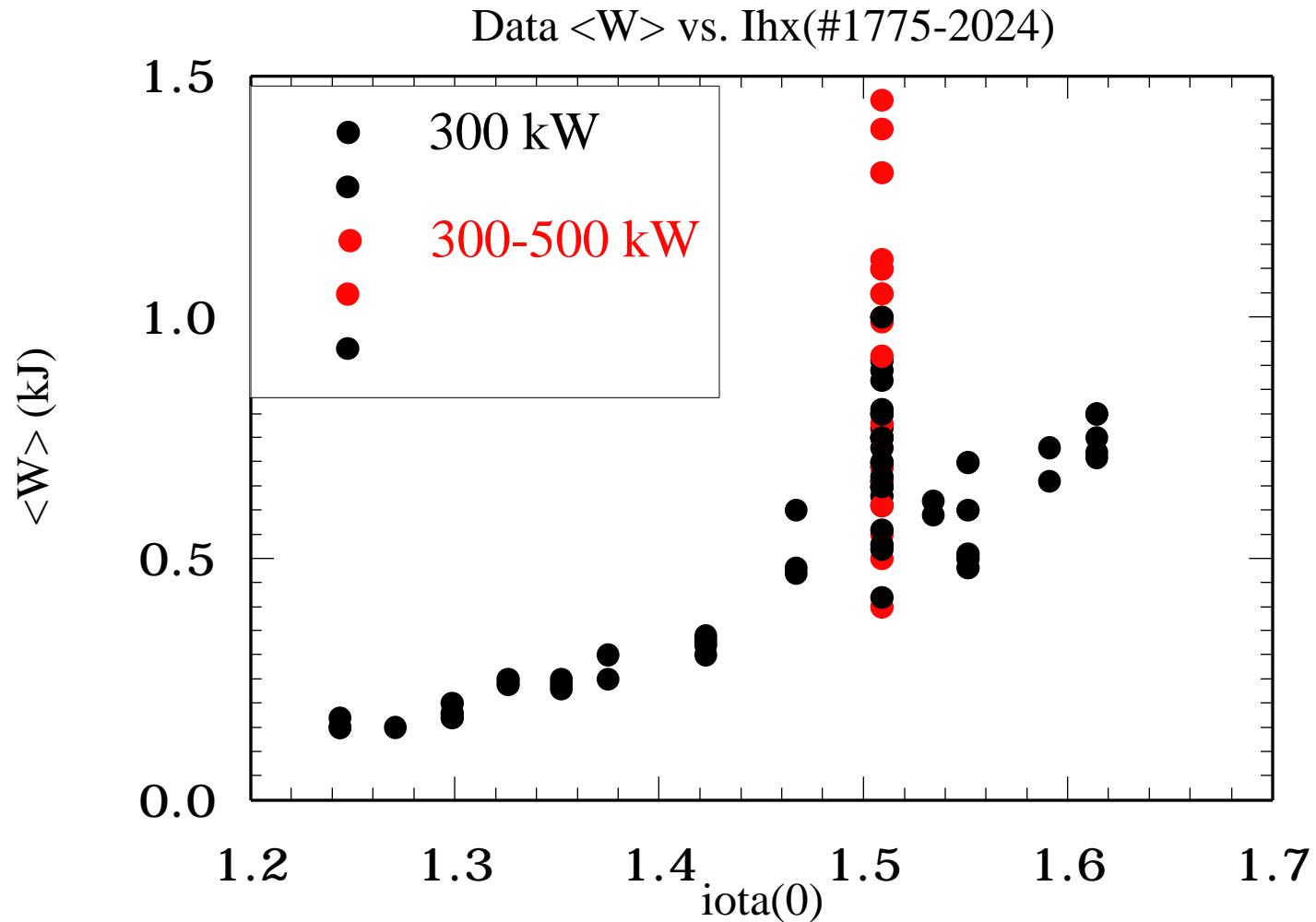


Peaked
temperature
and hollow
density profiles

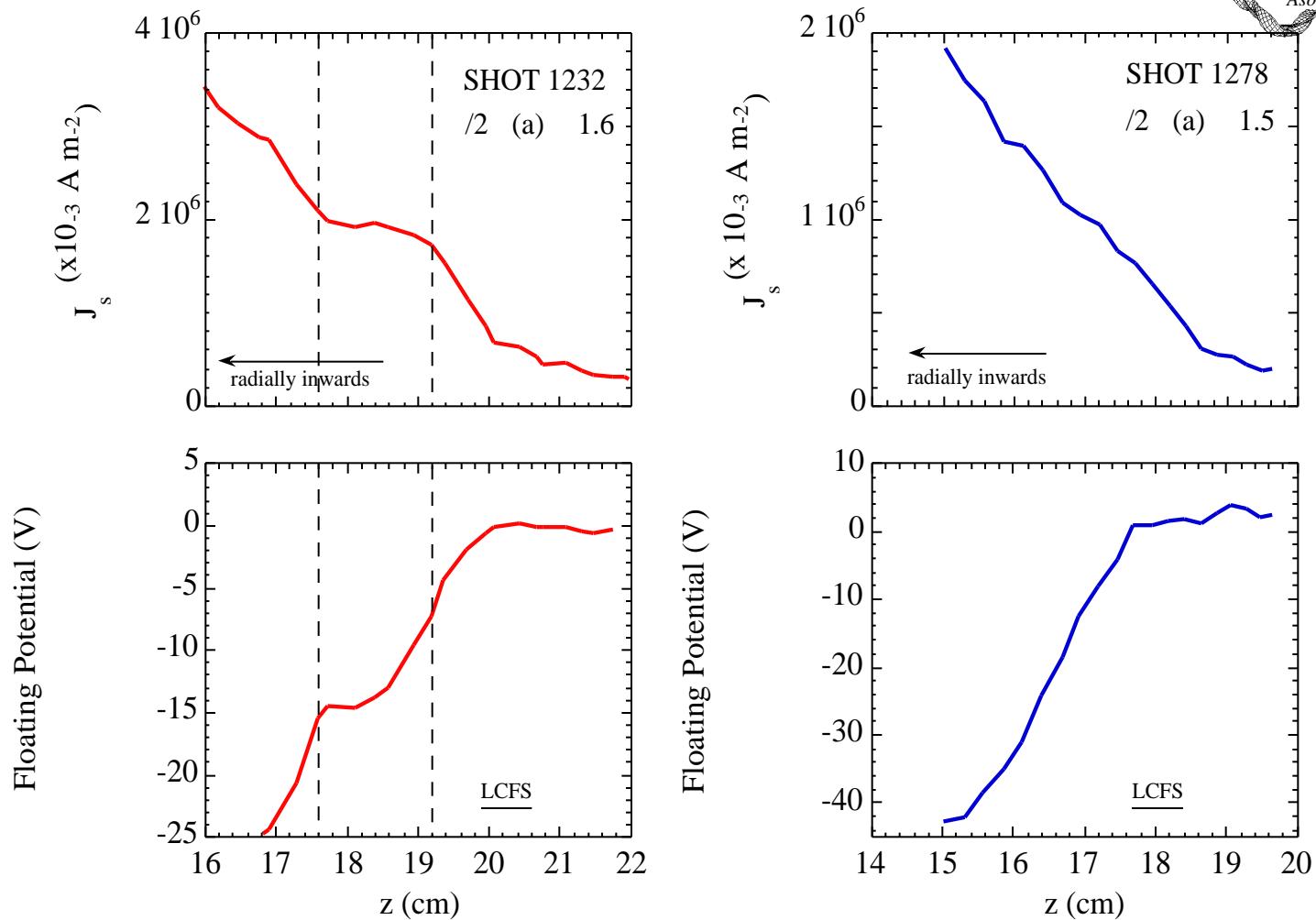
Transport analysis



Energy Scaling

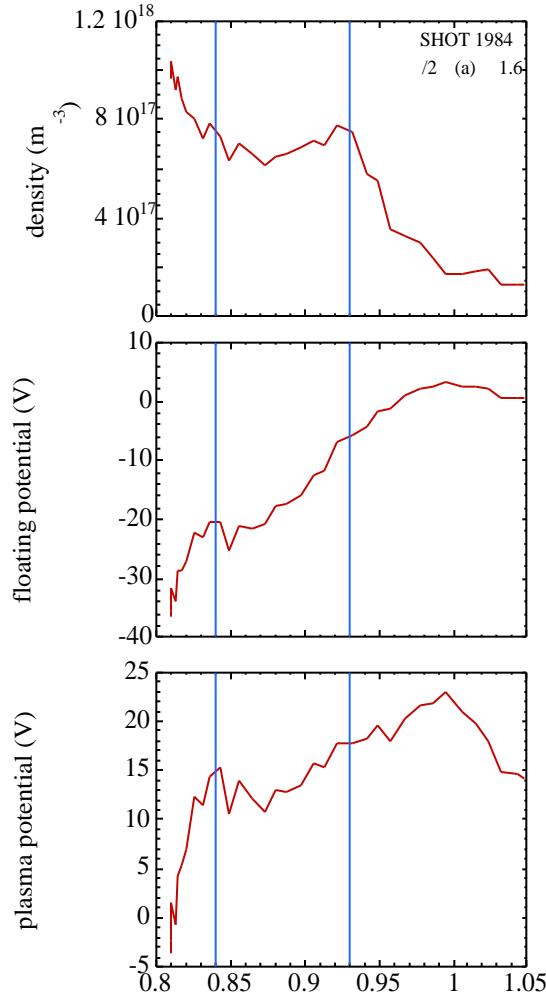


Plasma profiles and rational surfaces



Rational surfaces (8/5) have been observed as a
flattening in the edge profiles

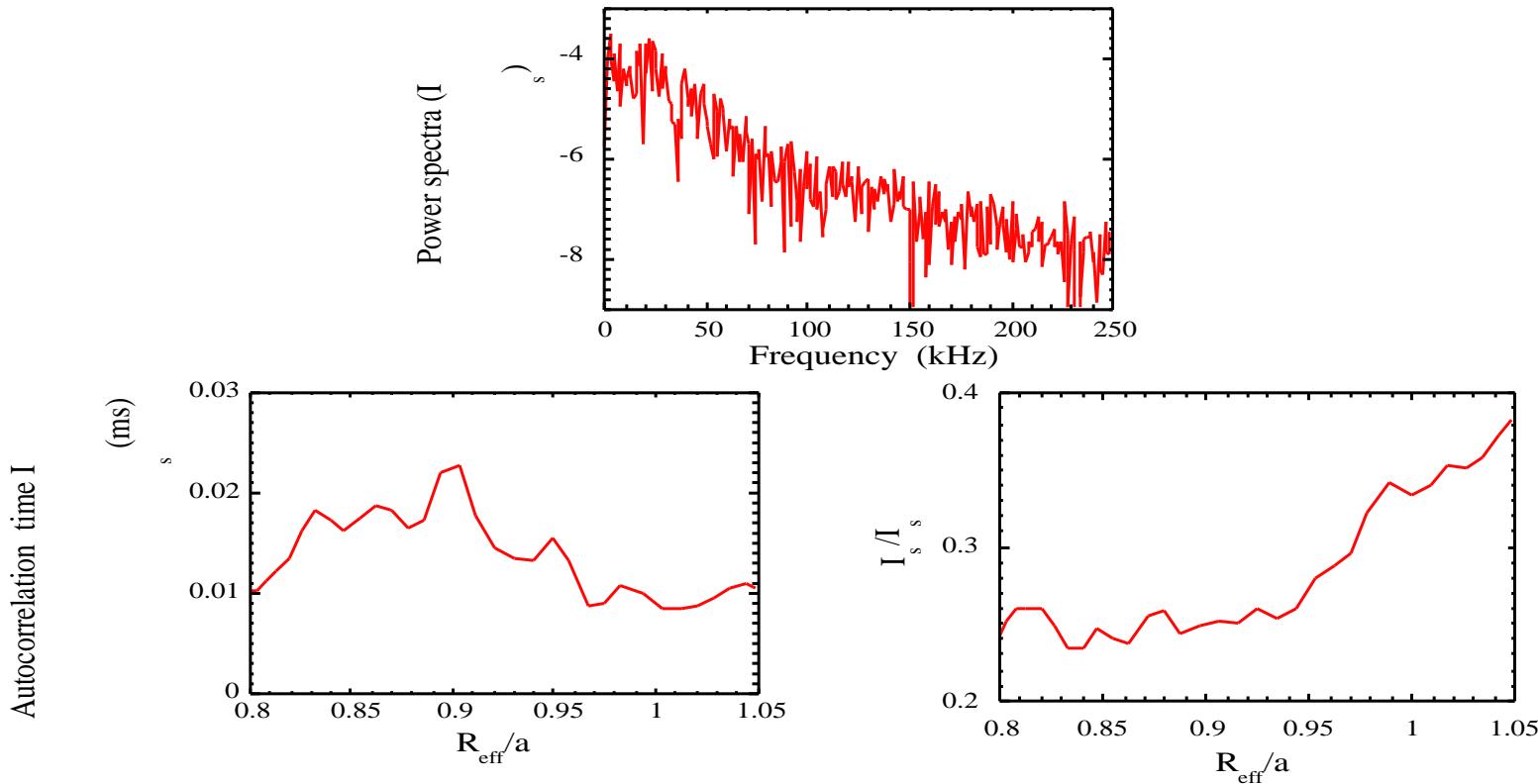
ExB sheared flows linked to rational surfaces



Strong radial variation in the plasma potential ($d\phi/dr \approx 0 -10^3 \text{ V/m}$).

This result can be interpreted as an increase of the sheared ExB flow linked to the radial location of the 8/5 rational surface:

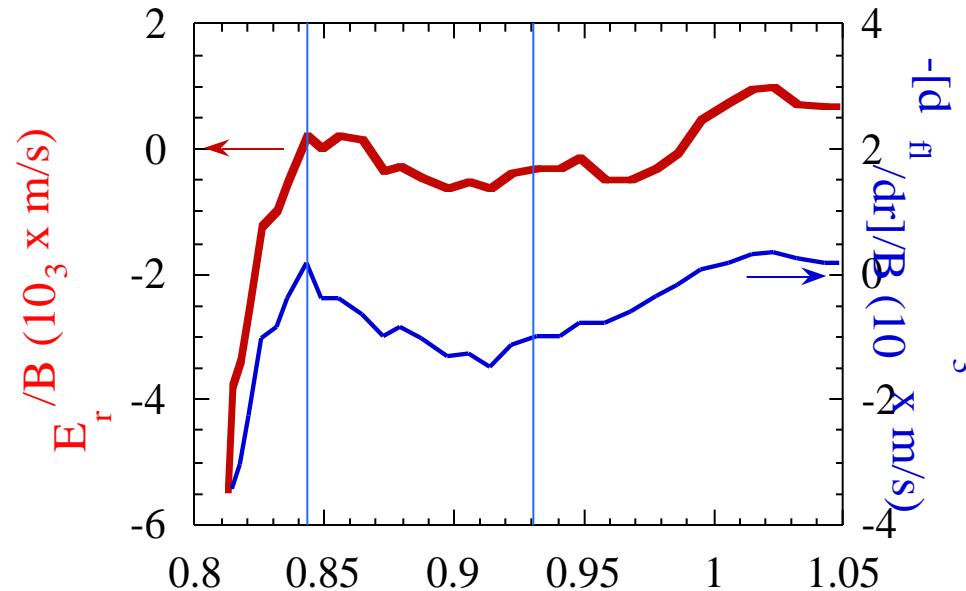
Edge fluctuations in TJ-II



Density fluctuations are in the range (0.2 - 0.4) with frequencies below 200 kHz.

The correlation time of fluctuations is in the range of 10 μ s (i.e. $1/\tau_c \approx 10^5$ s $^{-1}$).

ExB shearing rate at edge rational surface



The **ExB decorrelation shearing rate in the proximity of rational surfaces (8/5)** is in the range $\approx 10^5 \text{ s}^{-1}$ which is comparable to $1/\tau$, τ being the characteristic decorrelation time of fluctuations:

$$B^{-1}dE_r/dr \approx 1/\tau$$

Transport Barriers at Rational Surfaces



- The radial location of rational surfaces appears to play an important role to determine the generation of internal transport barriers: JT-60U, RTP, JET, ...
- The experimental evidence of ExB sheared flows linked to rational surfaces observed in TJ-II may help to explain the relation of transport barriers and rational surfaces in the core plasma region in fusion plasmas.

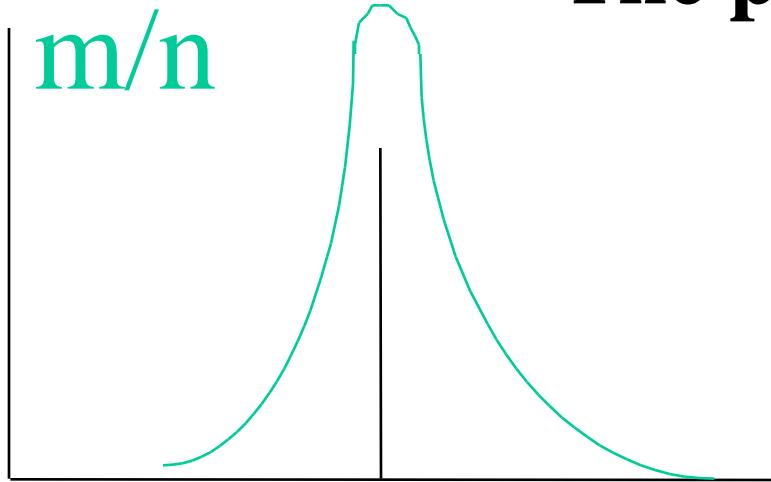
Motivation



**Why sheared ExB
flows at rational
surfaces?**

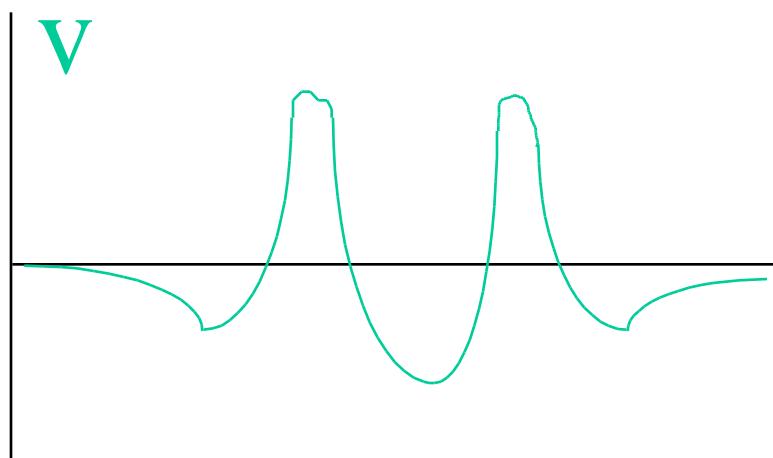
**Rational surface induced anisotropy in the structure of
turbulence (Reynolds stress) ???**

The physics concept



Fluctuations are expected to show a maximum amplitude at the rational surface.

Modification in the degree of anisotropy in the radial-poloidal structure of fluctuations



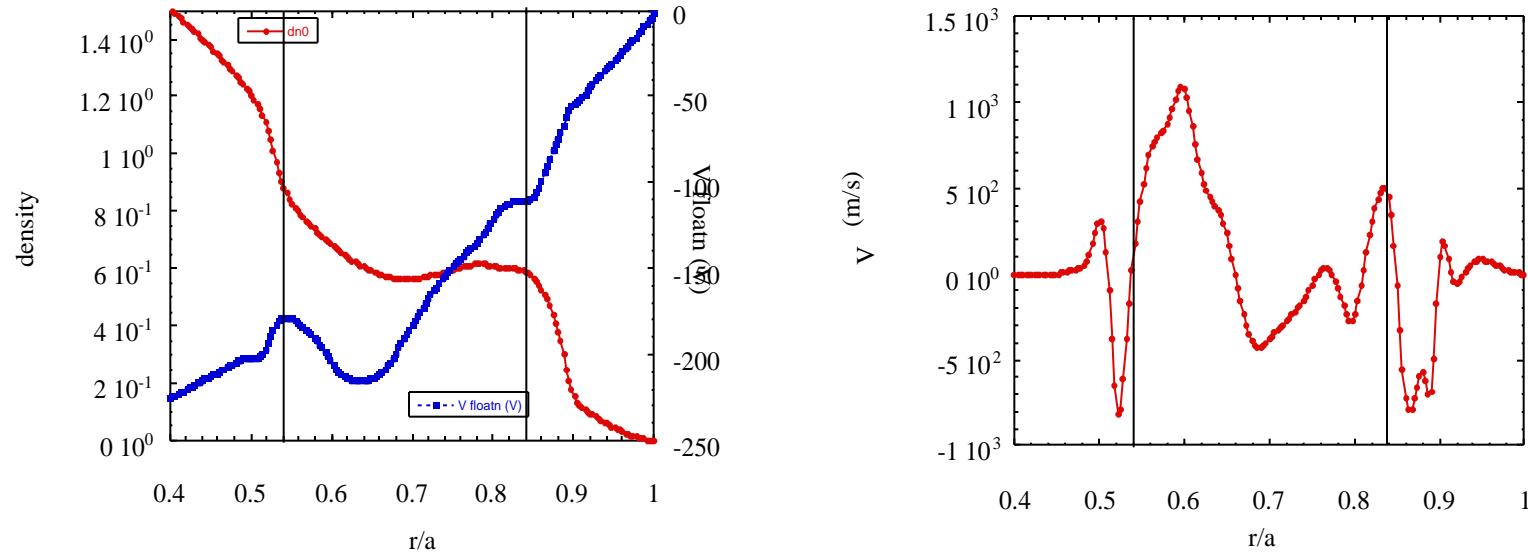
$$\frac{\partial}{\partial r} \langle \tilde{v}_r \tilde{v}_\theta \rangle > 0$$

Momentum re-distribution:

ExB

The modeling

(B.A. Carreras, V. Lynch, L. García, May 1999)



The effect of a magnetic island induced by resistive interchange modes on the radial structure of sheared flows driven by fluctuations via Reynolds stress have been investigated.

The radial structure of the poloidal flow shows two sharp spikes just outside the island region.

These results are consistent with the TJ-II experimental findings

Transport barriers at rational surfaces

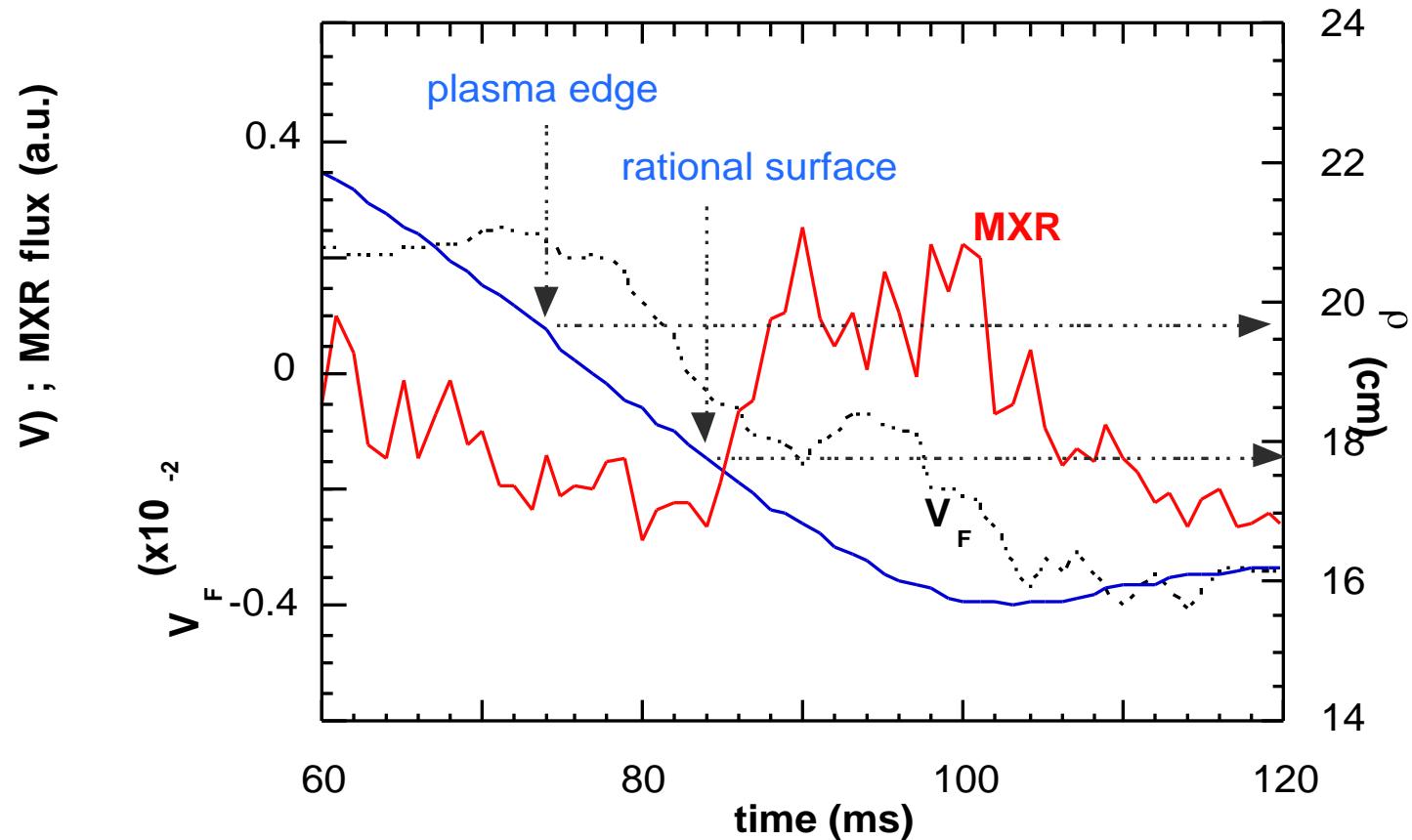


The radial location of rational surfaces appears to play an important role to determine the generation of internal transport barriers: JT-60U, RTP, JET, ...

The experimental evidence of $E \times B$ sheared flows linked to rational surfaces observed in TJ-II may explain the formation of transport barriers at rational surfaces in the core plasma region in fusion plasmas.

Fast Electrons Confinement

We have evidence that fast electrons are confined
in the vicinity of rational surfaces



Resonance surface studies



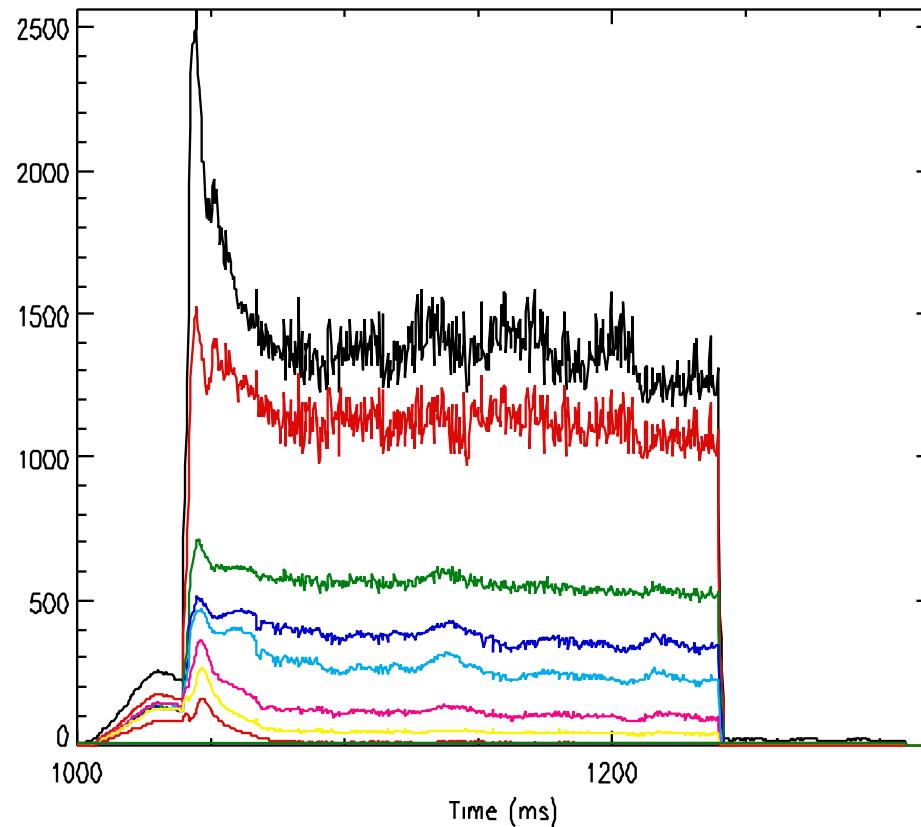
The role of ExB flows linked to rational surfaces on plasma profiles and confinement should be investigated in fusion plasmas (tokamaks, stellarators, RFPs)

This is a major research area in TJ-II:

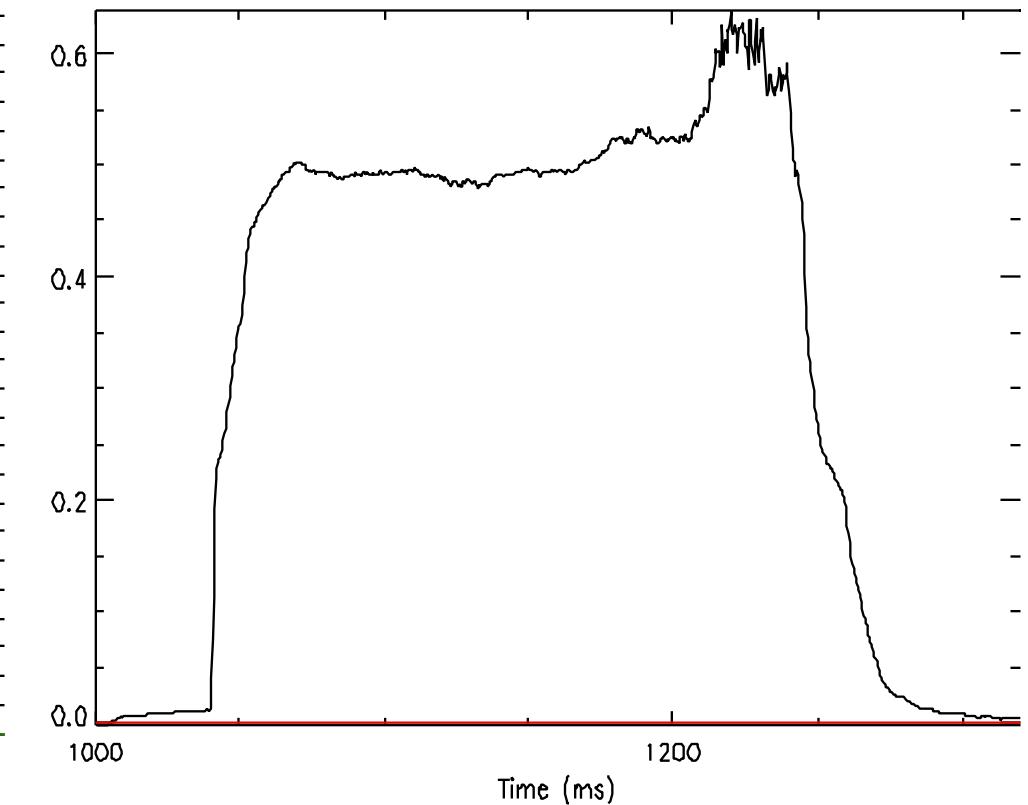
- Radial electric fields (HIBP, probes, spectroscopy)
- Plasma profiles: High resolution Thomson scattering, ECE....
- X-ray tomography
- Theoretical studies of ExB flows at rational surfaces, mhd...

Transport Barriers in TJ-II

T_e (eV) - ECE: 8 Channels



Line Density (10^{19} m^{-3})



$P_{ECRH}=300 \text{ kW}$. Narrow power deposition profile.

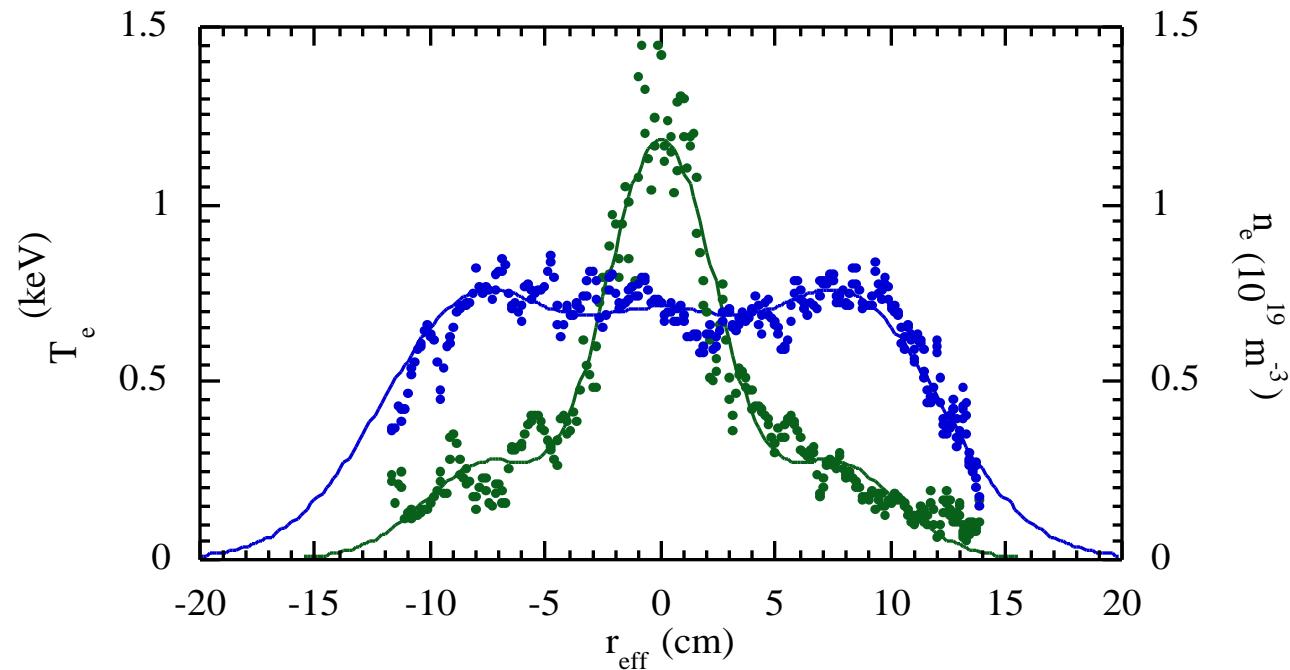
High temperature at the centre.

Low density discharge.

Transport Barriers in TJ-II



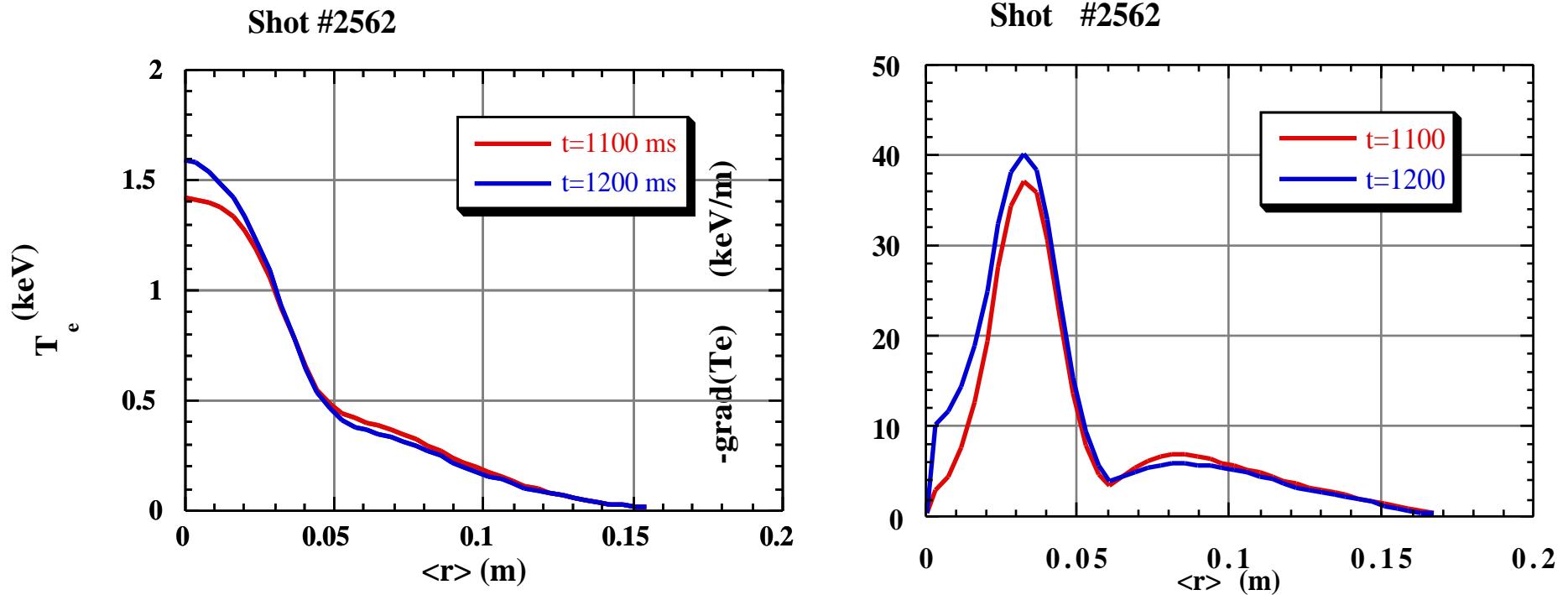
Thomson Scattering profiles.



Peaked temperature profile.

Hollow density profile.

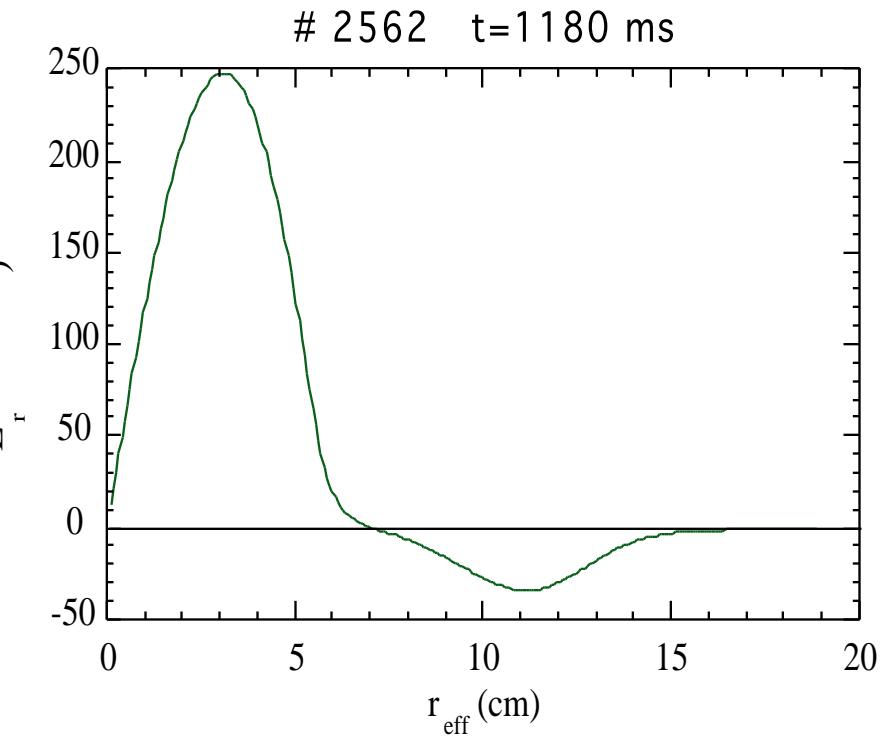
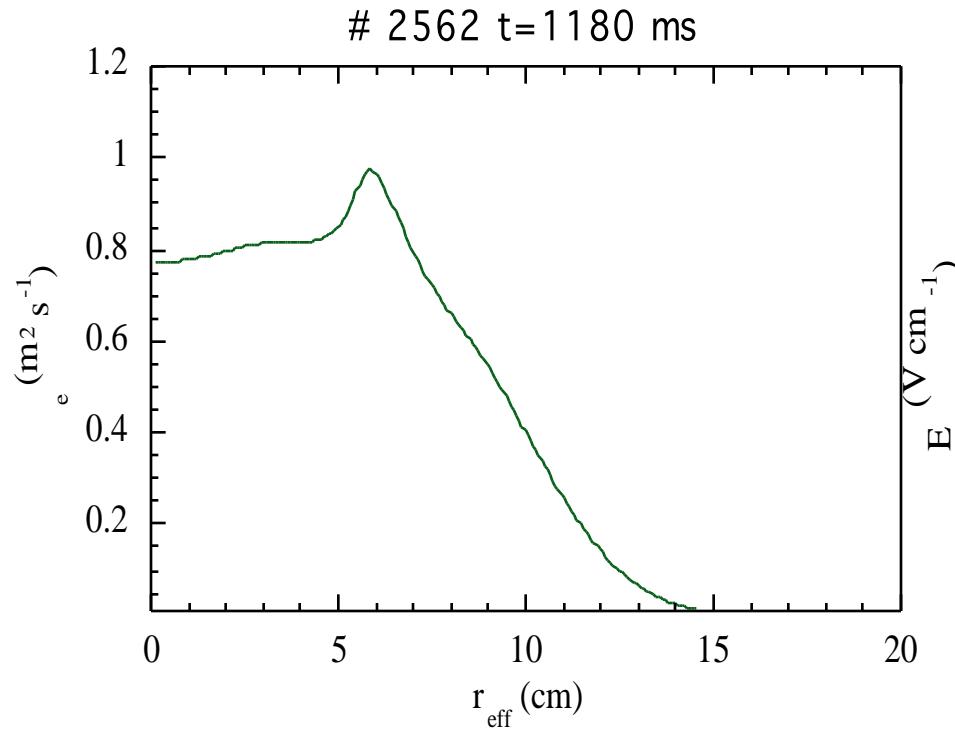
Transport Barriers



A high temperature gradient appears at plasma core.

Without this gradient, usual values of temperature should be expected ($T_0 \approx 1$ keV)

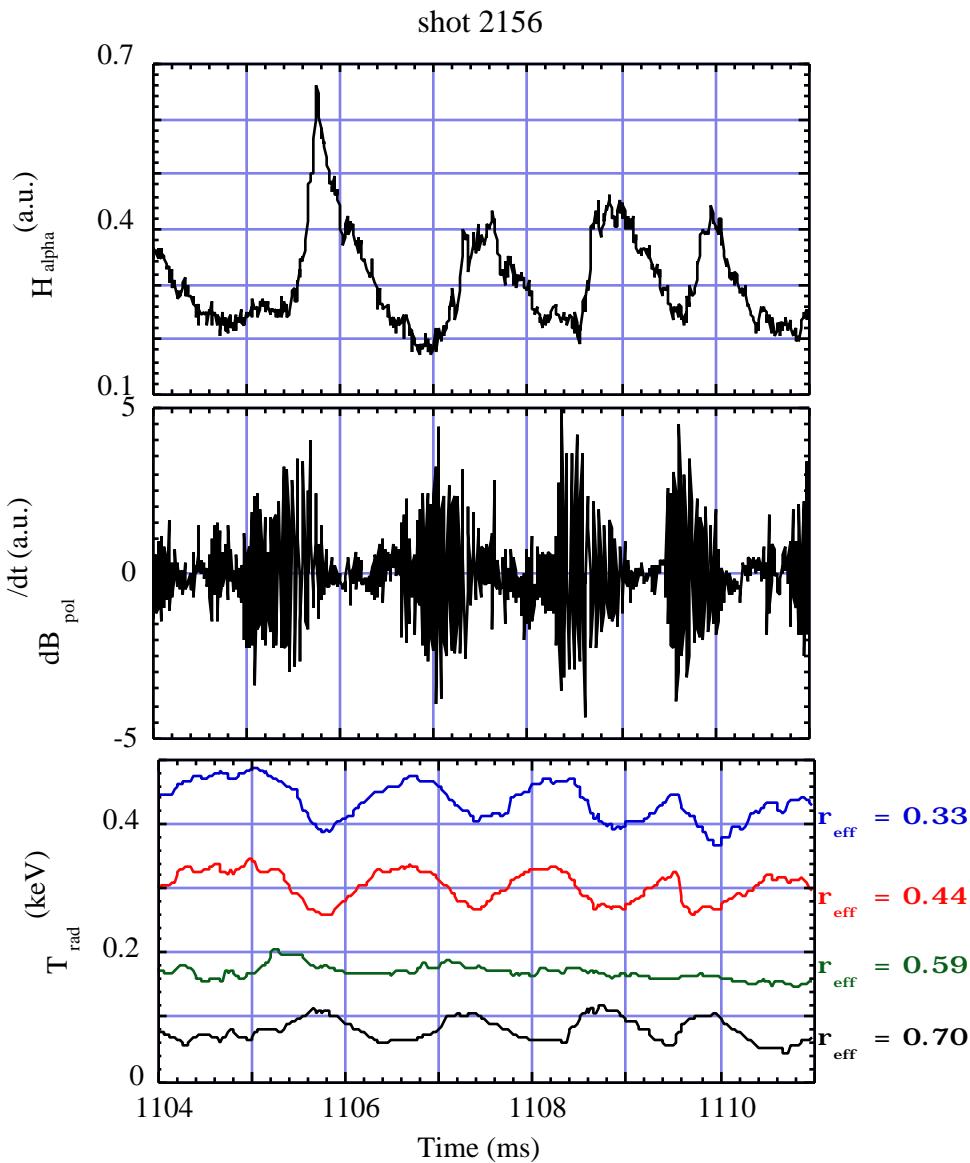
Neoclassical estimations



An extensive falling of χ at plasma core is predicted by neoclassical estimations, rather than a local one.

A strong positive ambipolar electric field appears (electron root).

MHD Activity



ELM-like features near the edge for high density and temperature plasmas are found:

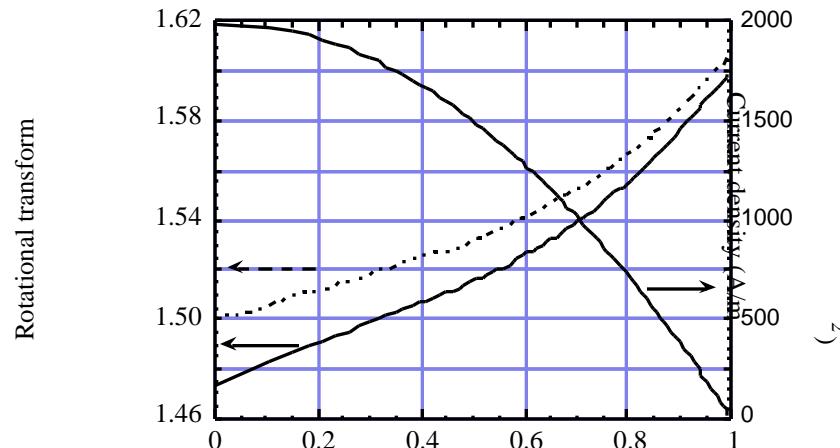
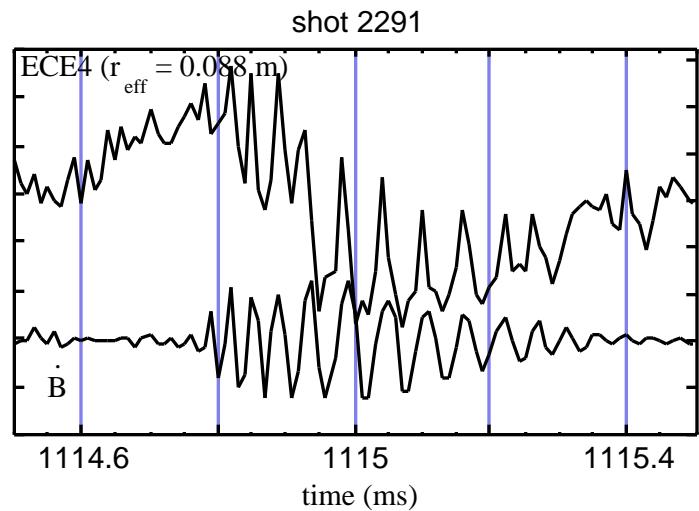
MHD (10-30 kHz) activity

Pivot point shown by the ECE radiometer about the $r_{\text{eff}}=0.6$

Sudden increase of H_{α} -emission

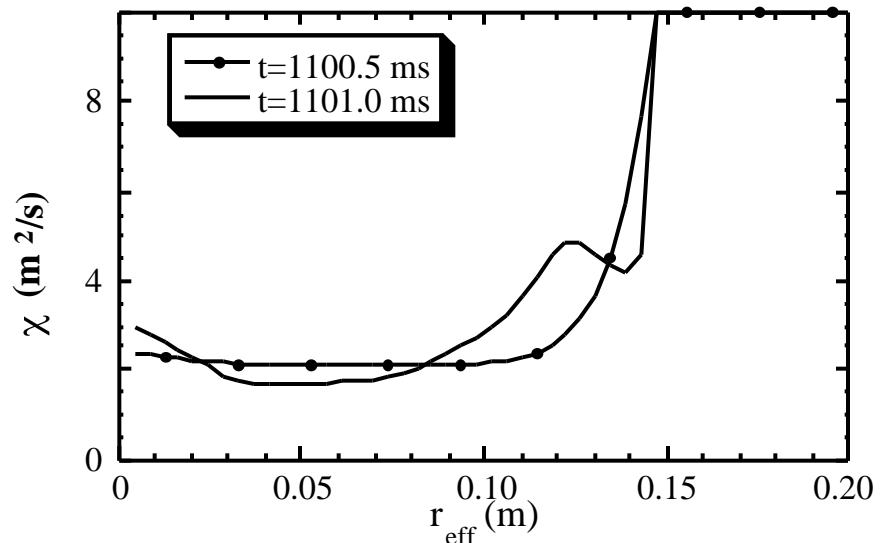
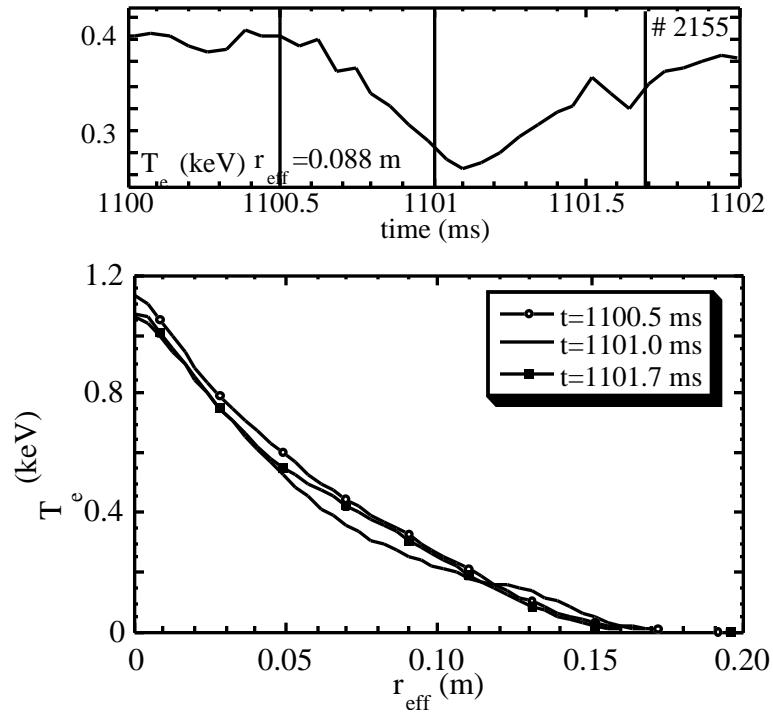
Cold pulse propagates towards the centre with $e = (2-4) \text{ m}^2/\text{s}$.

ELM-like activity



There is magnetic activity in the center of the plasma possibly associated to the $m=3, n=2$ internal resonance

ELM-like activity(cont'd)



This event triggers the elm-like mode in the outer part producing a flattening of the electron temperature. The transport is slightly increased in this outer region

Summary

- A flexible ECRH system is used with two gyrotrons (≤ 600 kW). NBI system under installation.
- Plasma discharges, using two transmission lines with power densities of 1 and 25 W/cm^3 , with central temperatures up to 1.5 keV have been achieved. Te profiles react to on-off axis heating.
- Configuration scan studies have shown a significant modifications in temperature plasma profiles and confinement in TJ-II. Energy scales with iota and volume.
- High resolution Thomson Scattering profile show fine structures.
- Transport barriers have been observed in low density discharges.
- ELM-like phenomena is clearly seen in high power discharges. Possible explanation is the interaction of $m=3/n=2$ mode with resistive ballooning instability.
- Evidence of sheared ExB flows and fast electrons confinement associated to the presence of rational surfaces has been observed in the of the TJ-II stellarator. This mechanism may explain the spontaneous formation of transport barrier at rational surfaces.